



<b>Title</b>	<b>Teaching introductory circuits and systems: enhancing learning experience via iterative design process and pre-/post-project learning activities</b>
<b>Author(s)</b>	<b>Lei, CU</b>
<b>Citation</b>	<b>The 2014 IEEE International Symposium on Circuits and Systems (ISCAS 2014), Melbourne, Australia, 1-5 June 2014, In IEEE International Symposium on Circuits and Systems Proceedings, 2014 , p. 2413-2416</b>
<b>Issued Date</b>	<b>2014</b>
<b>URL</b>	<b><a href="http://hdl.handle.net/10722/199381">http://hdl.handle.net/10722/199381</a></b>
<b>Rights</b>	<b>IEEE International Symposium on Circuits and Systems. Proceedings. Copyright © IEEE.</b>

# Teaching Introductory Circuits and Systems: Enhancing Learning Experience via Iterative Design Process and Pre-/Post-Project Learning Activities

Chi-Un Lei

Department of Electrical and Electronic Engineering  
The University of Hong Kong, Pokfulam Road, Hong Kong  
Email: culei@eee.hku.hk

**Abstract**—Project-based learning is commonly used in teaching contents of circuits and systems. In this paper, in order to facilitate students' learning in an existing project-based learning framework, two enhancements have been introduced: i) the pedagogical adoption of the iterative design process have been emphasized to further utilize the pedagogical value of the project vehicle; and ii) four pre-/post-project learning activities have been proposed to direct students' working in the project and learning in the course. An open-ended evaluation of the project has also been made.

## I. INTRODUCTION

Recently, design training and project-based learning have been widely adopted in teaching circuits and systems [1]–[8]. Studies show that this approach effectively attracts, engages and retains students' talent and interest of learning circuits and systems. Furthermore, through project-based learning, students learn to collaborate with peers, solve open-ended problems without clear definitions, and apply new content understanding with a greater flexibility. From the assessment perspective, this approach is also applicable to assess competence of students comprehensively. For example, CDIO (Conceive-Design-Implement-Operate) framework has been proposed to integrate the learning of a comprehensive set of personal and interpersonal skills, in addition to technical design skills with disciplinary knowledge [4]. Various project vehicles have been introduced to illustrate different teaching contents [3]–[10].

Besides project vehicles, pre-/post-project learning activities are complementary and necessary for learning. However, since project-based learning usually has a tight teaching schedule, adopted learning activities should be lean and effective. Yet, development of pre-/post-learning activities has not been investigated thoroughly in existing project-based learning frameworks (e.g. [3], [5], [9], [10]). As a result, the control and measure of learning effectiveness in the design project are limited by an inadequate assessment and pre-/post-project learning activities. For example, the CDIO framework has limited discussions in checking for students understanding and skills, as well as encouraging students self-direction and collaboration [4]. Furthermore, most discussions in existing studies are entirely devoted to the project vehicle itself, and very little is said about the pedagogical value of the design process in the project. As a result, students may not be directed to achieve the desired learning outcomes in the design project.

In this paper, we focus on the discussion about the rein-

forcement of the pedagogical value of the project and pre-/post-project learning activities through an adoption in an existing project-based learning course that teaches introductory circuits and systems [9], [10]. Section II describes how the pedagogical adoption of the iterative design process can be emphasized to further utilize the pedagogical value of the project vehicle. In Section III, four pre-/post-project learning activities have been proposed to help students facilitate and self-assess their development of technical expertise and general engineering skills, and eventually direct their working in the project and learning in the course. In particular, purpose and process of each introduced activities are explained. Finally, an open-ended evaluation of the project is shown in Section IV.

## II. REINFORCING THE PEDAGOGICAL VALUE IN THE PROJECT DESIGN PROCESS

The investigated course is an introductory electrical engineering course with a Rube Goldberg Machine design project. The main objective of the course is to retain student motivations to study electrical engineering and learn principles of circuits and systems. The project involves connected learning and assessment activities that take place over the whole semester (i.e., 15 teaching weeks), and the schedule is shown in Table I. It is worth noting that the course also contains a conventional instruction module which comprehensively introduces networking, computer systems and image processing. However, the discussion of the conventional instruction module is beyond the scope of the paper.

### A. Rube Goldberg Machine

Broadly speaking, the Rube Goldberg Machine can be defined as a machine designed to perform a simple task in an overly complex way. Technically speaking, the Rube Goldberg Machine can be defined as an intuitive and loosely conceived engineering system. Pedagogically speaking, the Rube Goldberg Machine design project can be used to trigger and maintain students motivations in learning because of its innovative, humorous and unconventional nature [10].

### B. Teaching Philosophy of the Course

Teaching is aimed to coach students to develop their own vision, reasoning, practical skills and the passion in acquiring knowledge, such that they can become problem solvers and autonomous learners at the end. Therefore, design project should

be an iterative process with experiencing and innovating. In order to achieve the aforementioned outcomes, iterative design process has been outlined throughout the course, such that students can learn more effectively in the project.

### C. Iterative Design Process in the Course

Iterative design process is a design methodology based on a cyclic process of prototyping, testing, analyzing, and refining a product or process [11]. The key concept of the iterative design process is to develop a prototype that can be evaluated through prompt tests, and feedback can be quickly incorporated into the next iteration of the design. The process is repeated (i.e. the design is evolved) until the fitness of the design has been achieved. For example, in designing electronic circuits, instead of assembling all components on a small circuit board at the beginning, electronic circuits are repeatedly implemented on a breadboard during intermediate stages. Iterative design process can facilitate the design process in various product development situations, and eventually improve functionality over the original design.

In the project, since freshmen have no experience in designing engineering systems, their design usually confronts the reality of unexpected system behaviors at the beginning of the course. Therefore, the iterative design process can help them realize that ideal design and analysis with theoretical models are always inadequate when confronted with practical implementation. By doing so, inconsistencies and non-legitimacy among requirements, designs, and implementations can be discovered by students in the early design stage. Furthermore, misunderstandings by students can also be revealed and regulated. Furthermore, this process enables students to leverage lessons learned, speed up the overall design process, and consolidate what they have learned from lectures.

In order to utilize the pedagogical benefit of the iterative design process, the course project should provide a large degree of freedom, such that students can radically change the design or even completely abandon old ideas, without worrying too much about minor specifications of the design. Therefore, Rube Goldberg Machine, which is an intuitive and loosely conceived engineering system, is an appropriately project vehicle for the iterative design process.

### D. The Role of the Course in the Curriculum of Circuits and Systems

The course is a compulsory course for electrical engineering undergraduates and an elective course for undergraduates from other engineering departments. Since it is a foundation course, there are no prerequisites for this course. However, students are expected to know about basic electrical laws. Among these students, most of them (e.g. 96.5% in the studied semester) are freshmen who do not receive any engineering training in the past. Because of the curriculum reformation, the course substitutes the previous course (Electric Circuits and Digital Logic). Meanwhile, the course is a prerequisite module for a few electronic courses, such as Electric and Electronic Circuits, Digital System Design, Electronic Devices and Circuits, and Electrical Energy Technology. We believe that the improvement of retention in the engineering field as well as development of engineering skills and attributes

TABLE I. THE SCHEDULE OF ACTIVITIES IN THE COURSE.

	Lectures	Learning activities	Assessment tools
1	Project overview Systems	Design prototyping	
2	Laboratory preview Electronic systems	In-class questioning	Student response system
3	Laboratory preview Electrical circuits (components)	Pre-project lab In-class questioning	Work sheet (instruments) Student response system
4	Electrical circuits (basic analysis)	Pre-project lab	Work sheet (switches)
5	Electrical circuits (advanced analysis)	Pre-project lab Idea cultivation	Work sheet (sensors) Probing questions
6	Electrical circuits (power analysis)	Pre-project lab	Work sheet (timers)
7	Digital circuits (logic gates)	Idea cultivation Progress monitoring Technical questioning	Probing questions Work sheet Checklist (project planning)
8	Digital circuits (Boolean algebra)	Progress monitoring In-class questioning	Checklist (creativity) Student response system
9	Digital circuits (Karnaugh map) Project facilitation	Interim presentation Progress monitoring In-class questioning	Presentation scoring guide Checklist (collaboration) Student response system
10	Digital circuits (digital systems)	Technical questioning Progress monitoring	Work sheet Checklist (problem solving)
11		Progress monitoring	Checklist (project implementation)
12			
13		Project demonstration	Demonstration scoring guide
14			
15		Technical questioning	Examination

are a long-term cultivation, therefore, introducing project-based learning in teaching circuits and systems can facilitate learning of students in intermediate or advanced topics related to circuits and systems.

### III. PRE-/POST-PROJECT LEARNING ACTIVITIES

With building the Rube Goldberg machine as the project vehicle, learning activities have been designed for students to promote a comprehensive learning. Specifically, theoretical concepts have been taught in lectures and tutorials. Moreover, a design prototyping exercise and pre-project laboratory sessions have been introduced before the project. Besides aforementioned learning activities, a competition has been used as the project demonstration, in order to serve both as an incentive to work hard, as well as an actual assessment criterion. In order to facilitate the overall learning, self-reflection and in-class questioning have been proposed.

#### A. Design Prototyping Exercise

A predigested fitness training exercise for the iterative project design process, Marshmallow Challenge [12], has been adopted in the first lecture. It involves the task of constructing the highest possible free-standing structure with a marshmallow on top. An example for the design prototyping exercise in the class is shown in Fig. 1. The structure must be completed within 18-minutes using only 20 sticks of spaghetti, one meter of tape, and one meter of string. Through the exercise, students can build up their collaboration, problem solving and creativity for their project. Furthermore, students can realize that i) debugging is an important stage in the design process, and ii) robustness is a significant criterion for a designed product. As a result, students reserve more time for debugging, and thus more groups can implement a functional machine at the end of



Fig. 1. An example for the design prototyping exercise.

What is the output expression of the following logic-circuit diagram?

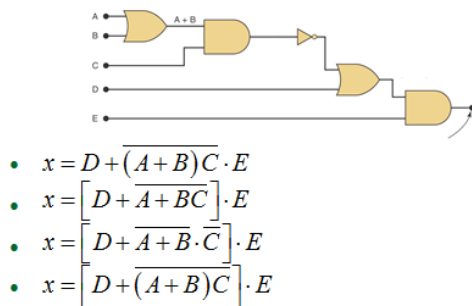


Fig. 2. An example for in-class questioning.

the course. This hands-on building exercise does not require advanced engineering skills; therefore, it is suitable to act as a preliminary exercise for the later machine design project.

### B. In-class Questioning

1) *Attributes:* Individual; Formative

2) *Purpose:* Instructors can probe for student understanding in the lesson, and clarify unclear concepts. Meanwhile, students can identify what they still need to understand. In addition, this assessment allows social friendly communication between instructors and students. In other words, the system can change students' learning experience and improve their lecture engagement because students can guide and affect classroom dynamics.

3) *Process:* Instructors have used a self-developed student response system (iClass [13]) to question students throughout lectures. Students have been given one minute to discuss with classmates and select an answer through pressing pre-installed buttons on the armrest of the seats in the lecture room. Teacher has given prompt feedback and has explained common misconceptions after each question. An example of an in-class question is shown in Fig. 2.

### C. Pre-Project Laboratory

1) *Attributes:* Group and individual; Mainly summative; Prior; Implementation skills; Process oriented; Specific to Electrical Engineering

2) *Purpose:* Students can acquire implementation skills that are useful to the design project. Also, students can construct stage prototypes that may be useful to the machine.

3) *Process:* In view of students' different background in circuit theories, four preliminary circuit design exercises have been prepared in pre-project laboratory sessions. In these exercises, students should demonstrate their ability of using equipment and designing the layout of circuitries for sensing, driving and timing. Therefore, students have to complete a laboratory worksheet for their work. Furthermore, students have been asked individually about the setup and the procedure of the experiment as well as the design of new experiments, such that all students are able to design and implement new triggering mechanisms for their projects. Students have been assessed as a group by the completeness of the laboratory session worksheet and the content of the oral questioning. Furthermore, constructive feedback has been given to students and weakness and potential problems in students' implemented circuits have been pointed out.

### D. Self Reflection

1) *Attributes:* Individual; Formative; Thorough; Posterior; Higher order thinking; Self-directed; Process oriented

2) *Purpose:* Students can assess their engineering learning and skills after the course, as well as reflect on methods for improvements in the future design process. Furthermore, the self-reflection has been acted as a metacognition process, which can help students find out how they initiate and undergo the design process. This metacognition process can help students to make a more effective strategic decision in the future. It has been proved that learning with metacognitions is effective in improving students' learning [14].

3) *Process:* At the end of the project, students have been asked to write an individual reflection report on their understanding of technical content. Questions are as follows:

- 1) *In less than 200 words, describe how the Rube Goldberg machine you and your partners have built for the course works? Starting from the push button, how does it lead to the final popping of the balloon?*
- 2) *In less than 300 words, describe your role in the project. What have you built? Which part of the design was your idea? Also, briefly explain how your group has divided the workload among members.*
- 3) *How does it help you to understand how circuit works?*

### E. Teaching Practices for Improving Student's Engagement

An engaged learning environment is needed for effective teaching and learning. Therefore, the following practices can be adopted to improve student's engagement in the course:

- Prompt in-class assignments are given to students, e.g. "The Muddiest/Clearest Point" and "Lesson's Attributes", such that students can conduct a "written" conversation with teachers about their learning.
- Enough quick recall are provided during classes and learning activities, in order to develop student's self-awareness about their acquired knowledge and dispel student's confusion as soon as possible.

- Quick and simple in-class questions that students can respond all at once by putting their fingers up, are raised to stimulate students' thinking, if there are no installed e-learning systems in the classroom.

#### IV. OPEN-ENDED EVALUATION OF THE PROJECT

A survey analysis is used to evaluate the students' perceptions about the project. Open-ended feedback comments from students and instructors have been collected. The enrollment for the course was 140 students in the studied semester. Among these students, 88 students have returned the survey, therefore the response rate is about 63%.

##### A. "Do you think the project has helped you in understanding how basic electronic circuit works?"

Most students responded positively. Only 4 out of 88 students disagreed. Summary of received comments are as follows:

- For students who disagreed, they claimed that too much focus and efforts were put into mechanical part rather than electrical. We observed that students did not realize that mechanical stages cannot help them in understanding basic electronic circuits and the course. Clear guidelines should be given to students next time, such that they mostly concern on significant parts.
- Pre-project laboratory sessions seem useful and practical, but some students were confused about how the sensors or actuators work after pre-project laboratory sessions. It would be better if basic theories of the components can be taught in lectures or tutorials. In other words, teaching should be compactly integrated with learning activities. However, introduction of extra materials is limited by the tight teaching schedule.
- Students thought that learning through a project is better than just listening during lectures. Electronic circuits are easy to understand through laboratories.
- Students mostly completed circuits by trial-and-error. Therefore, students discovered that debugging is a critical process in designing circuits and systems. Furthermore, it is worthwhile to use Marshmallow Challenge as a fitness training exercise for the project.

##### B. "Are there any comments related to laboratory sessions?"

Summary of received comments are as follows:

- Since groups were formed by four or five students, some students in a group may not fully immerse in each steps since there is only one set of equipment.
- Students suggested that more laboratory activities can be introduced to illustrate different electronic components and their applications. In particular, more complicated exercises can be tried out. This can help students fully understand the inner theory of the experiment circuit in the labs. However, introduction of lectures is limited by the tight teaching schedule.

##### C. "How do you like the project?"

Most students responded positively. Only 5 out of 88 students had "no fun" in the project and 1 being neutral. Summary of received comments are as follows:

- Four students thought that the project can improve areas beyond electronic knowledge, like creativity, teamwork and communication skill. Moreover, three students thought that the project allows students to conceive creative ideas.
- Through the project, students realized that design in practice is different from theoretical design.

#### V. CONCLUSION

In this paper, we have enhanced the efficiency of a project-based learning framework in teaching introductory circuits and systems. First, the pedagogical adoption of the iterative design process have been described to further utilize the pedagogical value of the project vehicle. Second, four pre-/post-project learning activities for the project have been proposed to assist students to direct their working in the project and learning in the curriculum of circuits and systems.

#### REFERENCES

- [1] R. Cheville, "Engineering education today: Capturing the afterlife of sisyphus in five snapshots," *Proceedings of the IEEE*, vol. 100, no. 13, pp. 1361–1375, May 2012.
- [2] D. W. Knight, L. E. Carlson, and J. F. Sullivan, "Improving engineering student retention through hands-on, team based, first-year design projects," in *Proc. International Conference on Research in Engineering Education*, Jun. 2007, pp. 1–13.
- [3] D. G. Lamar, "Experiences in the application of project-based learning in a switching-mode power supplies course," *IEEE Trans. Educ.*, vol. 55, no. 1, pp. 69–77, Feb. 2012.
- [4] E. Crawley, J. Malmqvist, S. Ostlund, and D. Brodeur, *Rethinking Engineering Education: The CDIO Approach*. Springer, 2007.
- [5] C.-S. Lee, J.-H. Su, K.-E. Lin, J.-H. Chang, and G.-H. Lin, "A project-based laboratory for learning embedded system design with industry support," *IEEE Trans. Educ.*, vol. 53, no. 2, pp. 173–181, May 2010.
- [6] C. Kellett, "A project-based learning approach to programmable logic design and computer architecture," *IEEE Trans. Educ.*, vol. 55, no. 3, pp. 378–383, Aug. 2012.
- [7] C.-U. Lei, N. Wong, and K. L. Man, "Integration of a wireless sensor network project for introductory circuits and systems teaching," in *Proc. IEEE Intl. Symp. on Circuits and Systems*, Jun. 2013, pp. 2569–2572.
- [8] C.-U. Lei, "Applying the problem-based learning approach in teaching digital integrated circuit design," in *Proc. Enhancing Learning Experiences in Higher Education: International Conference*, Dec. 2010.
- [9] C.-U. Lei, H. K.-H. So, E. Y. Lam, K. K.-Y. Wong, R. Y.-K. Kwok, and C. K. Chan, "Teaching introductory electrical engineering: a project-based learning experience," in *Proc. IEEE Intl. Conf. on Teaching, Assessment, and Learning for Engineering*, Aug. 2012, pp. 335–339.
- [10] C.-U. Lei, H.-N. Liang, and K. L. Man, "Advancements in using a machine design project for teaching introductory electrical engineering," in *Proc. IEEE Intl. Conf. on Teaching, Assessment, and Learning for Engineering*, Aug. 2013, pp. 556–559.
- [11] B. Boehm, "A spiral model of software development and enhancement," *Computer*, vol. 21, no. 5, pp. 61–72, 1988.
- [12] "Official website of The Marshmallow Challenge." [Online]. Available: <http://www.marshmallowchallenge.com/>
- [13] "Official website of The HKU iClass Project." [Online]. Available: <http://www.eee.hku.hk/~iclass/>
- [14] R. J. Marzano, *A theory-based meta-analysis of research on instruction*. Mid-continent Regional Educational Laboratory, U.S. Dept. of Education, 1998.